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Overview

Epidemiology of the sick building syndrome

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The sick building syndrome (SBS) has been the subject of serious scientific inquiry only in the past 10 years. It is commonly accepted to represent eye, nose, and throat irritation; headaches, lethargy, difficulty concentrating, and sometimes dizziness; nausea, chest tightness; and other symptoms. Evidence suggests that what is called the SBS is at least three separate entities, each of which has at least one cause. This review will summarize the epidemiologic investigations of the SBS and present an overview of etiologic hypotheses. (J ALLERGY CLIN IMMUNOL 1994;94:277-88.)

Key words: *Indoor air, epidemiology, occupational health, sick building syndrome*

Indoor air quality is of concern because most persons in the United States spend approximately 90% of their time indoors.[1] No federal health standards are applicable to indoor environments as criteria for adequate indoor air quality in the United States.[2] However, formal guidelines have been established in Europe.[3] Factors contributing to perceived indoor air quality include temperature, humidity, odors, air movement and ventilation, and bioaerosol and volatile organic hydrocarbon (VOC) contamination. Table I lists the factors that have been implicated. Many of these pollutant categories are addressed by specific engineering standards of the American Society of Heating Refrigerating and Air-conditioning Engineers (ASHRAE), the Illuminating Engineering Society, and the American National Standards Institute. Although they are not enforceable through federal or state agencies, they do define professional standards to which designers may be held. In addition, several states, including California, New Jersey, and Washington, have state laws regulating indoor air quality.

None of the professional standards and very little scientific literature address multiple exposures, that is, interactions of noise, lighting, thermal, and air quality. The effects and perceived severity of individual pollutant categories are also a function of work stress and organizational dysfunction, personality structure, and coping styles. Therefore even where dose-response relationships have been defined for individual pollutants, their likely effect and interactions in real-world settings are poorly documented.

Abbreviations used:

ASHRAE:	American Society of Heating Refrigerating and Air-conditioning Engineers
LASAS:	Linear Analog Self-assessment scale
NIOSH:	National Institute for Occupational Safety and Health
SBS:	Sick building syndrome
VOC:	Volatile organic compounds

The World Health Organization and Molhave have classified the range of complaints attributed to indoor air pollution, labeled the "sick building syndrome (SBS),"[1, 4, 5] into broad categories of mucous membrane irritation (eye, nose, and throat irritation), neurotoxic effects (headaches, fatigue, and irritability), asthma and asthma-like symptoms (chest tightness and wheezing), skin dryness and irritation, gastrointestinal complaints, and others. However, there is no generally accepted clinical definition of the SBS for individuals, at least in the United States, and it remains a diagnosis of exclusion. In contrast, in the Nordic countries, the "office eye syndrome," and other symptom groupings from the above list are recognized to cause office worker discomfort, ill health, and "disease." Whether some of these problems, particularly those involving mucosal irritation, may be attributable to exposure to allergens in

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TABLE I. Etiologic agents postulated for SBS

Specific environmental factors	
Bioaerosols	Mold spores
	Culturable organisms
	Cell fragments
	Secretions
VOC	Man-made products (carpets, carpet backing, paints and coatings, glues and caulks, laser printers, photocopiers, fax machines, etc.)
	Mold secretions (aldehydes, alcohols)
Dust	Bioaerosols
	Fibers
	Particulate organic matter
Thermal parameters	Temperature
	Relative humidity
	Draftiness
Lighting	Glare, contrast, and intensity
Sound and vibration	Acceleration
Workplace characteristics	
Inadequate engineering design	
Faulty installation	
Poor operations and maintenance	
Antiquated equipment	
Crowding	
Photoduplication	
Workplace organizational characteristics	
Job-related tension	
Job dissatisfaction	
Personal risk factors	
Gender	
Atopy	
Work stress	

susceptible individuals has been considered, but no good evidence for such cause and effect relationships exists.[6] This article will review studies of the SBS epidemiology as opposed to clinical investigations and chamber studies and summarize the etiologic hypotheses that have been discussed. It will not summarize the extensive number of single-building investigations because of space limitations.

CROSS-SECTIONAL EPIDEMIOLOGIC SURVEYS

The initial approaches to defining recognized new problems in occupational and environmental health have generally relied on cross-sectional epidemiologic surveys. A major limitation and methodologic difficulty of such field studies has always been the definition and adequate characterization of exposure. Two groups of field studies have been performed in indoor environments, those using buildings and those using individuals as the "sampling unit." Field studies are always imperfect, and the limitations of the sampling procedures restrict our ability to interpret or generalize the results.

All field studies that attempt to define the relationship between exposure and some biologic effect must characterize that exposure using industrial hygiene techniques, that is, they must define when, where, and how to obtain a measure of personal exposure. The investigators must then select an appropriate analytic method. Consider as an example the problem of measuring exposure to fungal particles in indoor air. A sampling strategy must be selected that will assess how many fungal particles are inhaled by subjects. A time unit for measurement of the delivered dose must be defined. It must be defined in such a way that it can be meaningfully related to some outcome, that is, symptoms or physiologic measures defined in the same time frame. One can attempt to establish such exposure by area sampling, for example, by placing a collection device in the general area frequented by the subject. Alterna-

tively, a collection device may be placed on the lapel of the subject near the nose. This has been termed "personal sampling," because it better represents the actual exposure of individuals. Personal sampling has long been recognized to represent a substantial improvement over area sampling.

However, most cross-sectional surveys have used only area sampling for exposure characterization. Rodes et al.[7] suggest that even local area sampling over an extended period is not representative of delivered inhaled dose because of the dilution effects of indoor air current direction and speed. This is reflected in a survey of personal diaries and sampling,[8] which suggests that even keeping activity logs and extrapolating exposures is an imprecise method of exposure assessment. Therefore most cross-sectional surveys were designed in a fashion that is unlikely to define accurate exposure-response relationships.

Sampling unit: Buildings and areas

Although building occupant symptoms very during the day and concentrations of various pollutants differ substantially over an 8-hour period, most authors have used exposure assessment techniques that do not respect the natural variability of symptoms and exposure. Most questionnaires inquire about the presence of symptoms in frequency categories of days per week, month or year, and measure exposures over an 8-hour period, expressed as an 8-hour time-weighted average area sample.

European studies

The first cross-sectional survey of building related complaints was conducted in the United Kingdom as a search for humidifier fever by Anthony Pickering. Finnegan et al.[9] arranged that physician-administered questionnaires be given to the occupants of nine buildings. Three buildings were naturally ventilated. Seven of these buildings were not known to have complaints and two, including one naturally ventilated structure, were reported to have an "excess" of work-associated complaints. Reports of nasal symptoms, such as congestion, pruritus, and rhinorrhea; eye symptoms, including tearing and pruritus; drying of mucous membranes; work-related chest tightness, wheezing, and shortness of breath; rash; and headache were sought. The prevalence of work-related headaches, lethargy, nasal and mucous membrane symptoms, and chest tightness was approximately double in workers from mechanically ventilated buildings. In buildings with humidification systems, surprisingly chest tightness and dry skin appeared more frequently.

In follow-up, the investigators questioned the office workers of two adjacent buildings differing in ventilation systems.[10] Several worker complaints were more common in the mechanically ventilated building. No differences were identified between average levels of temperature, relative and absolute humidity, air velocity, air ionization, carbon monoxide, ozone and formaldehyde concentrations in two rooms of the buildings. A subsequent investigation of the lighting in these same buildings suggested that natural lighting was associated with fewer reports of headache and lethargy during work.[11]

Also in the 1980s, Skov, Valbjørn, and the Danish Indoor Study Group conducted the Danish Town Hall Study.[12, 13] The indoor climates of 14 town halls and affiliated buildings together with questionnaires obtained from 4369 employees were assessed. As in the British study, employees were questioned for the presence of mucous membrane symptoms such as eye and nose irritation, nasal congestion, rhinorrhea, and sore throat, as well as more general symptoms such as fatigue, malaise, irritability, inability to concentrate, and headache. Characteristics of the work environment were examined in one room in each building using an area sample and included temperature, humidity, carbon dioxide concentration, formaldehyde and VOCs; airborne concentrations of dust, microorganisms, and fibers; static electricity; lighting; noise levels; housekeeping; and analysis of the building material and material used in office equipment. No significant differences existed between naturally and mechanically ventilated buildings, although the highest rates of mucous membrane irritation, headache, fatigue, and malaise occurred in structures that were mechanically ventilated. Mucosal irritation and general symptoms were associated with photoprinting, working at video display terminals, and handling carbonless paper. Clerical and social workers had higher rates of complaints than did professional workers.

A second large British study involved 4374 office workers in 42 office buildings.[14] Using a questionnaire validated for retest reliability, workers were asked about nasal congestion, rhinorrhea, eye irritation, headache, lethargy, difficulty breathing, chest tightness, and flulike symptoms. Work-related symptoms were very common, with 80% of the 92% of the workers who responded

TABLE II. Primary problem source in NIOSH indoor air quality investigations through 1993[42]*

Problem source	Frequency (%) (n = 203)
Inadequate ventilation	48.3
Internal sources of pollutants†	17.7
Entrainment of agents (combustion, odors, etc.) from outside the building‡	10
Humidity	4.4
Biologic agents§	3.5
Contamination of building fabric‖	3
Environmental tobacco smoke	2
Noise or lighting	1
Unknown	9.4

*Only one categories is listed per investigation. Thus, additional or contributory factors are not considered. The 203 buildings consisted of offices (75%), educational institutions (14.8%), and health care facilities (9.3%).
†For example, methyl alcohol from spirit duplicators, methacrylate from copiers, and sulfur dioxide from heating systems.
‡For example, motor vehicle exhaust, dust, or fumes from nearby construction.
§This includes fungi responsible specifically for hypersensitivity pneumonitis (3%) and one case of scabies infestation (0.5%).
‖This does not include investigations of asbestos-related problems. Examples include dermatitis from fibrous glass and formaldehyde exposure.

citing at least one complaint. Symptoms were more common in women than in men and were independently more frequent in clerical workers and secretaries than in technical and professional employees. Managers had the fewest symptoms. Workers in mechanically ventilated buildings had more symptoms, particularly in buildings that were humidified or air conditioned. The most common complaint was lethargy (57%), followed by nasal congestion (47%), dry throat (46%), and headache (46%). Complaints of chest tightness and difficulty breathing were the least common (9%) but were more common in buildings in which the heating or cooling was part of the mechanical ventilation process. Symptoms were generally more frequent in buildings in which air was chilled or humidified.

In all three studies complaints of lethargy, mucous membrane irritation, and headache were common. More important than mechanical ventilation was the presence of humidification and air cooling systems. Job category and gender were associated with the rate of symptoms. The Scandinavian study raised concern about pollution from building materials and furniture by reporting an increased incidence of mucous irritation with exposure to photoprinting, carbonless paper, and video display terminals.

Mendell and Smith[15] conducted a meta-analysis of these and three additional European cross-sectional studies. A surprisingly consistent mean 50% excess of mucosal and general work-related symptoms was identified in buildings with mechanical ventilation systems. This led to the formulation of three etiologic hypotheses: ventilation systems distribute pollutants, serve as sources of pollutants, or serve as markers of inadequate environmental control.

Studies in the United States

Numerous investigations have been conducted in the United States. Many studies were part of litigation efforts. In addition, building design, construction practices, and ventilation systems in the United States differ substantially from those in Europe. Therefore it may be difficult to compare U.S. and European studies. North American projects have tended to be investigations of "problems buildings." The largest series was investigated by the National Institute for Occupational Safety and Health.[16] Table II presents a frequency distribution of the primary causes implicated in that series.

A first U.S. cross-sectional study, called the California Healthy Building Pilot study, was presented at a recent ASHRAE seminar. The results of this investigation are as yet unpublished, although available.[17] Hedge et al.[18] have conducted a cross-sectional survey of 22 offices in New York State and presented preliminary results. Communication with the author suggested that completion of field work in all buildings led to a change in the results in that particulates and lighting appear more strongly related to symptoms than initially described.

One U.S. investigation of a set of five problem buildings, that is the Library of Congress and Environmental Protection Agency building, used

area sampling and symptom severity indicators of individuals in the vicinity of the samplers on the day of sampling in a successful attempt to relate environmental measures to symptoms.[19] Some relationship has been evident between measured dust and symptoms. These results may not be extrapolated to most buildings because the buildings were selected because of the presence of problems, which may or may not be the same as those seen in other problem buildings. Nevertheless, they are consistent with results of two other surveys implicating dust.

Subsequent cross-sectional studies

Only one cross-sectional study has actually measured ventilation rates and medical symptoms in a large sample of buildings.[20] Ventilation rates were not actively manipulated. This report was part of a larger investigation, and in this subset study, ventilation rates and other parameters of air quality were measured in 160 buildings in which 540 persons had completed symptom questionnaires. Ventilation rates, in general, were higher than newly adopted Swedish guidelines. There was strong correlation between lower ventilation rates and "general symptoms" such as fatigue, headache, nausea, and difficulty concentrating but less with mucous membrane symptoms such as eye irritation, stuffy and runny nose, throat discomfort, and cough. The sensation of "dry air" was correlated with general symptoms and outdoor flow rates but not with actual humidity. Thus these investigators recommended increasing ventilation rates.

Subsequently, several follow-up symptom survey studies without ventilation measurements have appeared in the United Kingdom. In addition, Norback et al. published two cross-sectional investigations, one of a series of "sick buildings[21] and one of personnel in schools.[22] In both, "personal" factors such as "nonspecific hyper-reactivity" (defined as a positive response to that question on a questionnaire) and a work dissatisfaction index were strongly related to the level of complaints. In the school investigation, the levels of VOCs were also related to complaints. In the "sick" building study, atopy did not correlate with symptoms, but atopy was assessed only through subject questionnaire.

Zweers et al.[23] studied more 7000 occupants of 61 buildings and presented the results in 1990, with formal publication in 1992. These authors found relationships between symptoms and air conditioning and humidification. In addition, video display terminal use, crowding, gender, and "allergies" (defined by a positive response to that item in a questionnaire) were associated with more symptoms. Individuals with more frequent work-related symptoms also used more sick time.

Finally, Anderssen et al.[24] conducted a mail survey of randomly selected homes in Sweden. Houses were more likely associated with complaints if they were built after 1975 and if they housed multiple families.

Cross-sectional surveys: Microenvironmental measures

A major problem with most field investigations is that environmental exposures were characterized with area samples. In an analogy to engineering work examining thermal comfort, Jannsen[25] investigated offices using a Likert scale–based acceptability questionnaire and measured pollutants locally at the same time. He was unable to identify a relationship.

Hodgson et al.[26] have published a series of papers using a sampling strategy developed from that approach and using a questionnaire modeled after early kindergarten studies in Denmark.[27] Symptoms were characterized with a questionnaire using a *l*inear *a*nalog *s*elf-*a*ssessment *s*cale (LASAS) at the time of the investigation. At the same time, industrial hygiene measures of pollutants were obtained with direct reading or short-term sampling instrumentation. Collection of both exposure and effect data at the same point in time was thought to allow the development of direct relationships.

In an initial attempt to explore the use of the method, Hodgson et al.[28] described an investigation in which a walk-through had suggested *a priori* that vibration was a primary contributor to complaints. The office in question was situated above a poorly anchored chilled water pump. A 12-inch I-beam connected the pump base to the metal floor beams and transmitted vibration so that the fluid meniscus in coffee cups could be observed to vibrate. The method identified acceleration, a vibration parameter, and temperature as the primary contributors to complaints, suggesting the method was valid for the designated purpose.

A second investigation was undertaken in another problem building that had recently been constructed. That investigation[29] identified particulates, lighting, and the length of ductwork from the central heating, ventilation, and air conditioning units to desks as primary contributors to complaints. A follow-up investigation had too little power to determine the effect of remediation.

Subsequently, the authors undertook a similar investigation[30] of 145 office workers in five buildings without known problems, all research administration offices in the Pittsburgh area. Again, a LASAS questionnaire and environmental measures were obtained simultaneously. Lighting, concentration of VOC, and length of time spent at the desk were primary predictors of complaints. In addition, the presence of perimeter fan-induction units was weakly associated with symptoms.

Finally, the authors examined central nervous system complaints (headaches, fatigue, irritability, and difficulty concentrating) in a study of 205 office workers[31] with the LASAS instrument, with more sophisticated measures of the indoor environment and with a validated work stress questionnaire.[32, 33] Eight buildings were studied: two previously had complaints but had undergone remediation, three were known to have some minor complaints among occupants, and three were thought to have no occupant dissatisfaction. Surprisingly, the highest level of self-reported symptoms was identified in a building in the third category. The single strongest predictor of symptoms was job-related tension. Although other stress factors demonstrated a very clear dose-response relationship and appeared related when examined individually and plotted, they no longer appeared to play a role when tension was examined with regression models. Their strongly significant relationship was thought to be from the consistency of this relationship rather than the overall explanatory power. Sound pressure levels and VOCs also influenced the level of general symptoms.

Jannsen and the Pittsburgh group used similar approaches but different outcome instruments. Jannsen studied acceptability and Hodgson et al. studied medically defined symptoms. Jannsen did not examine work stress. The implication of this investigation is that situations exist in which symptoms may not be related to either work stress or the physical environment alone but to both independently.

Conclusion: Field epidemiology

One interpretation of two different study approaches is that SBS symptoms are associated with mechanical ventilation through one of three factors: (1) inadequate ventilation fails to dilute the pollutants that are generated and emitted indoors. This implicates VOCs as the primary sources of complaints. The consequence of this interpretation is that selection of low-emitting office products, introduction of paints and caulks with low emissions, and other forms of "source control" are the appropriate intervention for SBS. (2) Mechanical ventilation is a marker of system complexity and poor building performance, that is, buildings with mechanical ventilation maintain inadequate control over temperature and humidity excursions or have less adequate lighting and sound control than buildings with "natural" ventilation. (3) Finally, ventilation systems themselves may be sources of pollutants. Inadequate filtration allows dirt to accumulate, inadequate moisture control contributes water, and microbial growth ensues. Either microbial agents (culturable or not), their fragments, or secretions are the direct sources of complaints. Intervention and prevention strategies should then focus on operations and maintenance.

A separate interpretation is that the SBS is a term used for inadequately defined specific syndromes. Contributors to symptoms may occur on a building level, related to environmental exposures, on a personal level, related to intersubject differences in response, and on a workplace organizational level, on the basis of organizational function and stress. The primary etiologic agents include VOCs and microbial agents, although substantially more data support the former. Most authors consider the problem resulting from a variety of factors and do not attribute the etiology to one or the other.

EXPERIMENTAL STUDIES OF BUILDING ENVIRONMENTS

In 1988 Fanger[34] defined a new unit of pollution, "olf" (for olfactory), in an effort to quantify subjective air pollution emanating from persons. He arbitrarily defined one "olf" as the emission rate of air pollutants from a "standard" person, a white male working at one met (one metabolic equivalent, i.e., expending the energy required to sit at rest), aged 18 to 30 years, showering 0.7 time per day, and wearing no perfumes. The number of olfs was to be measured on initial perception of the odor. The pollution unit combined discomfort from irritation, annoyance from odor, and subjective overall acceptability. Panels of raters were trained in the laboratory and were taken to the field sites for assessment. The method has been criticized because it evaluates a pollution atmosphere within minutes after the measurement panel has entered the site to be judged. Odor annoyance is most severe early after first exposure and recedes over time, whereas discomfort from irritation is likely to increase over time. In addition, according to discussion with members of the

laboratory, up to 75% of the general population may not be able to rate odors consistently enough to be trained in the use of the method. This raises questions about whether the method can have general validity. Finally, the size of panels and the number of field tests they may perform without "recalibration" in the field have not been justified, and the data are accessible only in Danish. Nevertheless, it is a very interesting approach to acceptability ratings and provides a tempting alternative strategy.

Fanger et al.[35] used this method in a project designed to eliminate the psychosocial factors that might influence symptom reports by workers of buildings under study. Fifty-four judges who were not employed in the buildings under study entered 20 randomly selected offices and assembly halls in Copenhagen and assessed the air quality when the buildings were occupied, with and without operating ventilating systems, and when they were unoccupied. In this manner the investigators were able to separate the contribution of perceived air quality from that of occupants versus furnishing materials versus ventilation systems. They found that 20% of the perceived defects in air quality were due to building materials, 42% to ventilation systems, 25% to smoking and other occupant activities, and only 13% to the occupants themselves. Subsequent studies have suggested that the range of emission rates of malodorous substances from individual classes of sources vary widely, by almost one order of magnitude. Thus this study suggests that not just one factor contributes to air quality and the common work-related complaints grouped under the name SBS, that multiple sources must be considered, and that source control is as important an aspect of indoor air quality as ventilation.

The method has been incorporated into new Ventilation Guidelines for Europe,[36] a concept publication of the European Community on how indoor ventilation should be addressed in the future. It defines and describes cost tradeoffs between ventilation rates, acceptability, and complaints and demonstrates that "you get what you pay for." That is, decreasing and increasing ventilation has a cost and a benefit, and only local decision-making will allow reasonable tradeoff of comfort, productivity, health status, and economics.

Ventilation rates

The Swedish Office Building Project was described previously. It examined in a cross-sectional fashion the relationship between ventilation and complaint rates and considered a relationship present. That buildings were not reexamined after manipulation of ventilation rates is one weakness in the design of this landmark study.

Menzies et al.[37, 38] drew the opposite conclusions when they manipulated ventilation rates in a series of office buildings. In the experiment reported in the *New England Journal of Medicine*, they tested the hypothesis that symptoms attributed to the SBS would be reduced by increasing the outdoor air supply from 30 to 64 cubic feet per minute per person. Two buildings with sealed windows and mechanical ventilation but without a history of excess problems with indoor air quality were selected for study. During a 6-week period, the ventilation level was maintained for 1-week periods at 30 or 64 cubic feet per minute per person of outdoor air. Each ventilation level was repeated three times in random order. Workers completed questionnaires on symptoms each week, with 84% of 1838 eligible workers participating, and 82% of these completing the weekly questionnaires. Workers could not identify the changes in ventilation level despite significant changes in carbon dioxide levels and of indoor contaminants between the two rates. No significant association existed between symptom reports and ventilation level, although some authors are concerned with ventilation measurement methods, and other aspects of the study.[39] Pollutant concentrations did change. Office workers perceive changes in the relative humidity. The buildings were not known to have problems: only 20% to 30% of buildings are thought to have widespread occupant dissatisfaction from air pollution. Interestingly, "atopic illness," presumably identified by participant questionnaire, was significantly associated with symptom reports with an odds ratio of 1.4.

The study also stands in stark contrast to the experience of many researchers. For example, Nagda[40] found an association between decreased outdoor air supply and symptoms. Even cross-sectional surveys also have demonstrated weak association. Two factors may be important. First, increasing ventilation rates in the ranges used by Menzies et al. may be important only to address adverse effects of environmental tobacco smoke. For example, Cain[41] suggests that ventilation in that range may be necessary to modify odor annoyance. Second, other pollutant sources requiring such ventilation may be relatively uncommon. Specifically, the ASHRAE ventilation standard recognizes that 20 cubic feet per minute per person of outdoor air is adequate for many

sources. Woods et al.[42] have suggested that 75% of contributors to occupant indoor environmental satisfaction are lighting, thermal parameters, and acoustics and not merely "air quality." Therefore the ventilation in these buildings was better than that in most buildings in North America, and it would have been surprising if an effect could have been documented.

Other interventions

One of the earliest intervention studies in fact compared lighting intervention and ventilation increases in a single building.[43] Occupants were not aware that an intervention would occur. One group had lighting alone modified, the other both lighting and ventilation rate. Lighting and ventilation increases independently diminished occupant complaints.

Several studies have attempted to characterize the effects of ionization on symptoms. Robertson et al.[11] and Daniels[44] were unsuccessful. Daniels conducted an elegant crossover design trial and failed to show effects. The intervention by Wyon described below suggests that ionization per se may not be the important effect but that charging particles and using the room as a giant electrostatic precipitator may in fact be effective in reducing complaints.

Wyon[45] conducted an experimental study of a "sick" hospital in Malmo, Sweden, with a complex experimental study design. More than 25% of the workers had filed a compensation claim for SBS. The study intervened in a rigorous fashion using changes in ventilation rate, lowering temperature, installation of local air cleaners, changing glare, humdification, and installation of ionizers and wall collection plates. Sham interventions were conducted to maintain blinding among occupants. The author also measured particulate levels. A beneficial effect was noted for ionization with collection plates, even though the "specific pollutants" had not been identified. Particulate and symptom levels decreased measurably. The author concluded that successful intervention is possible even in the absence of final and true knowledge.

Reinikainen et al.[46] investigated humidification in a 6-week crossover trial. They were able to document a beneficial effect of humidification.

Conclusion: Experimental studies

In general, ventilation rates have been only inconsistently associated with symptoms of the SBS. A variety of interventions have been shown to affect symptoms and complaint rates. None have reduced complaints to zero. If the SBS has more than one cause, as many investigators hypothesize, it is not likely to be remedied by a single intervention.

POPULATION-BASED QUESTIONNAIRE SURVEYS

Two authors have conducted population-based questionnaire surveys in an attempt to identify the true population prevalence of the problem. Woods et al.[47] suggested that complaints occurred in more than half of the individuals in a stratified random sample of U.S. adults. Those with complaints demonstrated an approximately 20% decrement in productivity. Kroeling[48] completed a population-based survey of 2000 adults in Germany. He too documented a high prevalence of complaints and an approximately 50% excess rate of upper respiratory tract disease. He also suggested that complaints were more frequent in buildings with mechanical ventilation systems. In addition, wider ranges of temperature and vibration frequencies were noted in buildings with higher complaint rates, suggesting the possibility that signal-noise ratios were important in leading office workers to describe discomfort.

ANECDOTAL INVESTIGATIONS

Several publications have summarized series of investigations. One major problem with such "case series" is their lack of generalizability. Although some specific cause is identified and the problem attributed to that cause, the certainty that any specific complaints can be attributed to that cause is poorly defined. Because no follow-up studies of complaints after targeted intervention on the putative problem have documented that complaints subsided, the true etiology remains uncertain.

The National Institute for Occupational Safety and Health (NIOSH) has conducted more than 1000 investigations of buildings.[49] At least for the first several hundred buildings, no standardized protocol was used. In addition, NIOSH publications attribute complaints to one primary specific problem without listing potential additional causes in the summaries or providing criteria for defining that one etiology. Therefore the NIOSH studies should not be interpreted to indicate that only one aspect of the building was causing the problem. Table II lists the usual frequency distribution. "Ventilation adequacy" is generally not defined in the publications, and ventilation rates

and ventilation efficiency were not measured formally in the vast majority of investigations.

More important, other authors have identified multiple independent engineering deficiencies besides "inadequate ventilation" in problem buildings. Woods[50] suggests that on average at least three deficiencies were present in problem buildings. These include inadequate ventilation system design, instrument installation problems, inadequate maintenance, and misguided operational strategies. Such problems are likely both to decrease exhaust ventilation of pollutants generated within occupied space and to contribute to the development of pollutants within systems.

SPECIFIC POLLUTANT CATEGORIES

Specific factors have been implicated in the etiology of the SBS. Most authors no longer expect one single cause to explain most complaints, but rather assume that factors interact to cause occupant complaints. This section reviews the importance of specific pollutant groups.

VOCs

The term *VOC* refers to aerosolized hydrocarbons that are present in indoor air at room temperature. Sources of these molecules include building products such as paints, coatings, caulks, and carpet glues. Office products such as typewriter correction fluids, photoduplication and laser printing toners and their thermal degradation products, and carbonless copy paper release VOCs.[4, 51] In addition, perfumes, emissions from dry-cleaned clothes, and other products associated with human beings may give of VOCs.[52, 53] Finally, microorganisms including fungi may produce VOCs. The evidence for VOC contributing to SBS is summarized elsewhere in these proceedings.[54]

Bioaerosols

A body of engineering literature suggests that microbial agents may contribute to complaints. Inadequate dirt management and inadequate moisture control may lead to microbial proliferation. Dirt accumulates in ducts and on heating, ventilation, and air conditioning systems because of inadequate filtration. Water incursion into buildings is common, arising from three different mechanisms: leaks through the building envelope, inadequate humidity control, and inadequate sealing of the buildings against water vapor. Some contribution may arise from nocturnal off-cycling of ventilation systems.[55] Similar microbial flora are seen growing in ducts and office carpeting. Newer evidence suggests that office workers bring antigen in from home on their clothes, including dust mites, cats, and cockroach. In addition, microscopic evaluation of the dust indicated other potential antigenic components. Because atopic individuals have been thought to have a higher frequency of office-building-related-complaints,[23, 38] questions on the mechanism of such problems have developed. This topic is reviewed elsewhere in these proceedings.

The epidemiologic evidence is sparse. At least one group of authors indicate that their work supports such a hypothesis, although careful scrutiny of the tables in the manuscript and review of their explanation fails to confirm their conclusions.[56] One outbreak of asthma was identified in a building associated with excess symptom rates consistent with the SBS.[57] Also, outbreaks of hypersensitivity pneumonitis frequently have associated higher rates of symptoms not generally associated with hypersensitivity pneumonitis. Finally, a single nested case-control study failed to provide evidence supported atopy or bioaerosol exposure as contributing to SBS symptoms,[58] although cross-sectional surveys and clinical experience clearly support such an association.

Environmental tobacco smoke

Smoking is not permitted in most office buildings in the United States. Therefore environmental tobacco smoke is of little importance as a source of air pollutants. In other countries, tobacco smoke has been found to be a major predictor of occupant complaints.[34, 59] In the United States, as recently as 1988, 28.5 million (36.5%) of the U.S. nonsmoking workforce (79.2 million) worked in locations that permitted smoking. Of these 12.4 million (43.5%) reported some or moderate and 4.5 million (15.7%) great discomfort from environmental tobacco smoke.

The ventilation rates recommended under ASHRAE's ventilation standard are recognized to be inadequate to prevent annoyance and irritation from environmental tobacco smoke. Additional efforts, such as air cleaning with air washers, are necessary. Ultimate source control, as suggested by the Occupational Health and Safety Administration and the Environmental Protection Agency, involves banning tobacco smoke in public buildings.

Work stress

Work stress has been recognized as a potential-cause of discomfort in buildings.[60] Initial evalua-

tions indicated that a component might be mass psychogenic illness, and at least one investigation makes a strong argument for such an outbreak.[61] On the other hand, the scientific literature suggests that mass psychogenic illness in the workplace is a symptom of underlying work stress and not a disease in and of itself. Manifestations of work-related stress should lead to organizational analysis and an intervention in the structure of work places.

Several surveys have identified work stress as an important contributor to SBS symptoms. In a study of nonproblem buildings Hodgson et al.[30] suggested that work stress characterized with a validated instrument was able to explain twice as much of the symptom variance as environmental factors that could be quantified. Investigations of individual buildings with recognized problems and documented associations between some exposure and symptoms[62] were also able to document such relationships.

More important, an investigation of SBS symptoms and work stress suggested that the persistence of exposures and symptoms led to the development of work stress that might have been prevented with appropriate intervention.[63] An accompanying editorial suggests that such constellations may be important for many diseases.[64] In fact "stress" has been shown to affect response rates even to validated questionnaires.[65] In addition, the concept of "illness behavior" as defined by Mechanic suggests that personal factors are of great importance in the way individuals perceive and respond to the same external factors.

The person–environment-fit model of work stress suggests that individual personality style, coping skills, and the organizational environment contribute independently. Uniformly, questionnaires that define work stress are completed by individuals experiencing stress. No investigations have identified workplace characteristics that contribute, such as ambiguous assignments by supervisors, increased work pace and workload, or lack of supervisor support. In fact, no validated instrument exists to define the organizational characteristics that are recognized to contribute to "stress." Each of the three components provides investigators with a different intervention possibility, none of which have been formally attempted.[66]

Ergonomics

The experience of investigators in field surveys of problem buildings suggests that additional factors may be important. Although thermal comfort has been poorly studied in cross-sectional investigations, many specific problems in buildings have been attributed to inadequate comfort control. In addition, there is long-standing recognition of the importance of office ergonomics in contributing to SBS symptoms.[67]

SUMMARY AND CONCLUSIONS

Headache, eye, nose, and throat irritation, lethargy and fatigue, and rhinitis and bronchospastic symptoms have been attributed to indoor air pollutants. Nevertheless, a number of different pollutant categories clearly contribute to such symptoms. Although bioaerosols have been considered a cause of some symptoms, there is little valid scientific work in this area. Still, dirt and water management through housekeeping, filtration, and dehumidification are effective intervention strategies. More work supports the importance of VOCs emitted from office furnishings, wall and floor coverings, and office machines. The latter implies an imbalance between ventilation requirements and delivered ventilation. Defining and solving the problem of occupant complaints will require carefully controlled broad-based intervention studies.

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